THE IMPACT OF EUROPEAN SETTLEMENT ON BLUE OAK (*QUERCUS DOUGLASII*) REGENERATION AND RECRUITMENT IN THE TEHACHAPI MOUNTAINS, CALIFORNIA

SCOTT A. MENSING
Department of Geography, University of California, Berkeley, CA 94720

ABSTRACT

Absence of blue oak (*Quercus douglasii* Hook. & Arn.) saplings and seedlings has been noted throughout much of the species range. Our ability to assess whether the present poor regeneration is a natural pattern or a response to human induced environmental change is limited by lack of data on the history of blue oak recruitment. In this study, stand age analysis is used to reconstruct former patterns of blue oak regeneration and recruitment in three blue oak woodlands on the Tejon Ranch, Kern County, California. Analysis of 279 cross-sections showed that 56% of all stems sampled were recruited in 1856. Prior to 1856, recruitment was relatively continuous. Only 3% of all stems stems aged date to the period from 1864 to the present. Analysis of fire scars found an increase in fire frequency during the 1850's and 60's, followed by a distinct decrease in fires for a 70 year period. Differing patterns of regeneration were found to coincide with changes in local land use. During Indian occupation of the area, the woodland appears to have been less dense, with a slow but steady process of replacement, adequate to maintain the woodland. Changes in fire frequency and browsing patterns, associated with European settlement in the mid-19th century, resulted in unusually high rates of regeneration and recruitment. Since the 1860's, commercial livestock grazing, reduction of fire frequency, and an increase in density have resulted in virtually complete suppression of regeneration.

Recent assessments of blue oak (*Quercus douglasii* Hook. & Arn.) regeneration in California have found that recruitment of saplings to trees appears insufficient at the present time to replace many existing stands (Muick and Bartolome 1987; Bolsinger 1988). Stand age analyses have identified several periods of successful regeneration and recruitment since the mid-1800's. Evidence of blue oak recruitment during the period from 1860–1900 has been found in Monterey County (White 1966), Sequoia National Park (Vankat and Major 1978), Yuba County and Tulare County (McClaran 1986). McClaran (1986) also found a period of successful regeneration on grazed sites in Tulare county between 1890–1940. At each site, a lack of regeneration has been noticed since the early 1900's, except the grazed sites in Tulare county where recruitment declined after 1940.

White (1966) noted that European settlement during the late 1800's produced a period of dynamic land use, but felt that the changes

MADROÑO, Vol. 39, No. 1, pp. 36–46, 1992

were too varied to identify which factors may have affected regeneration. Vankat and Major (1978) suggested that successful regeneration occurred at a time when the Indian presence was diminishing and livestock grazing was increasing. They hypothesized that successful regeneration was initiated by livestock grazing, which both removed competing herbaceous species and decreased fuel levels, resulting in less intense fires. McClaran (1986) found no clear relationship between livestock grazing and regeneration; however, fire had a positive effect, with 70–85% of the trees becoming established within one year after a fire.

Because of insufficient data on the long term regeneration history of blue oak, it is unclear whether the present pattern represents a natural cycle, or a response to environmental change associated with European settlement (Bartolome et al. 1987). The record of tree establishment prior to 1860 is poorly documented, because of both natural tree mortality and because study sites have been located in areas of extensive settlement where clearing has occurred. Recognition of natural patterns of regeneration and recruitment are also complicated by the ability of blue oak to resprout following cutting. In this study an area of woodland is examined that has been undisturbed by cutting throughout the period of European settlement. The presence of many very large trees at the site also provided the potential for obtaining a long temporal record. Evidence is presented that suggests regeneration was relatively continuous prior to European settlement in the mid-1800's, but has been generally absent since the late part of that century. Local land use and fire history are examined to explain the effect of land use on blue oak regeneration and recruitment.

Study Site and Methods

Location and physical description. Tejon Ranch is located east of Lebec in the Tehachapi Mountains in southern Kern County (Fig. 1). The ranch has been held as a single property since the 1860's, and includes some of the largest undisturbed oak woodlands in the state. The study area is at the southern edge of the range of blue oak. Three sites were chosen which had been selectively cut for firewood between 1982 and 1987. Tree cover was pure blue oak with an herbaceous understory. The sites were between 975–1150 m elevation, on Anaverde gravelly loam and Walong sandy loam (USDA Soil Conservation Service 1981). Slope averaged from 20–25% with aspects of 45, 210, and 320 degrees. Sites each covered approximately 2.5 hectares, with a tree density of 224, 173, and 163 trees per hectare before cutting.

Collection of cross-sections. Cross-sections were collected from a total of 279 stumps. To test whether a subsample of stumps rep-

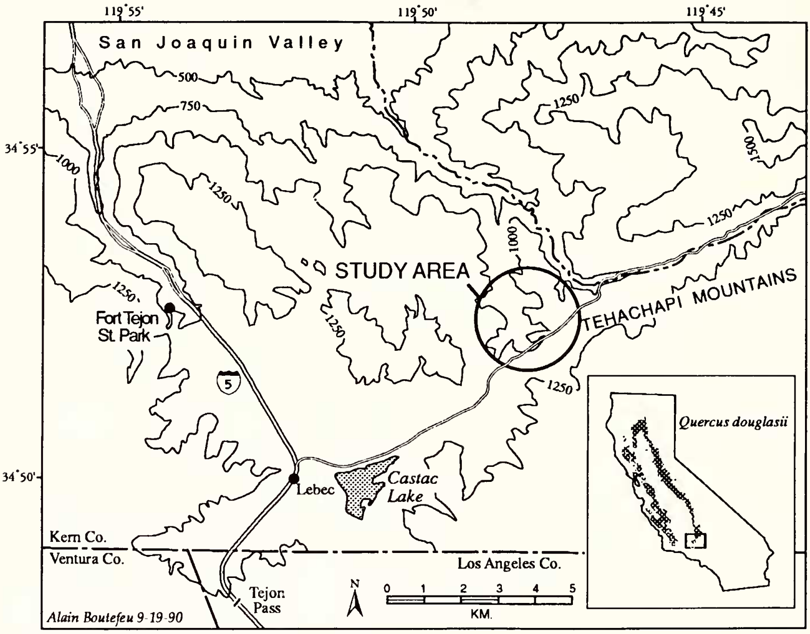

FIG. 1. Study area at the Tejon Ranch, near Lebec, Kern County, California. Contours are in meters. Inset map of the distribution of *Quercus douglasii* is after Griffin and Critchfield (1972).

resented the stand as a whole, sites were randomly sampled using the point-quarter method (Cottam and Curtis 1956), including standing and cut trees. Tree basal diameter was measured, and four broad size classes were identified: <20 cm; 20–<45 cm; 45–<70 cm; and 70 cm and over. The percentage frequency distribution for each size class in the stand was determined, and compared with the available stumps on each site. Adequate numbers of stumps were available in all size classes to cut one hundred cross-sections from each stand; however, only stumps that appeared solid to the center were collected. On site "B" only 90 cross-sections were collected because heart-rot in the largest size class (70 cm and over) reduced the number of usable stumps. For the same reason, only 89 cross-sections were collected from site "C". On site "A", there were not enough stumps available in the smallest size class (<20 cm) because the woodcutters had avoided smaller trees. This shortage was supplemented by collecting cores from ten randomly selected trees.

Stumps were cut at or below ground level in order to obtain the oldest possible age count, since it has been shown that samples taken from higher up the stem give younger dates (McClaran 1986; Harvey

1989). To achieve this, the surrounding soil was excavated to ground level on the downhill side before cutting.

Tree ring analysis. Cross-sections and cores were prepared and analyzed at the University of California, Berkeley, Department of Forestry laboratory. Samples were planed, sanded with 400 grit, wetted with water and counted under a 10–30× binocular dissecting microscope. Marker rings of narrow and wide growth patterns were identified as a cross-check for counting annual rings (Fritts 1976). Tree rings were counted along two separate axes. In a few cases where ring growth was wide and marker rings were easily identified, a single count was assumed to be sufficient. In cases where two counts produced different ages, these were averaged to provide a single date for analysis. The greatest error rate for differing counts was 2 years per 100 years. Where multiple centers were present in an individual cross-section, the number of centers was counted.

Fire history. Fire scars were identified and ages determined. Scars were cross-dated by comparing clearly identifiable ring sequences between cross-sections as suggested by McBride (1983). Following McBride and Jacobs (1980), mean fire interval (Romme 1980) was calculated by site, for three different land use periods. The earliest period (pre-1842), predates European settlement and reflects aboriginal burning. Period two (1843–1865) represents a settlement transition period during which European activity dramatically increased in the area, but the Mexican land grants were not occupied and utilized by the owners. The final period, (1866 to the present) is characterized by a commercial interest in the property, continuous livestock grazing, and fire control efforts.

Results

Tree recruitment. The ability of blue oak to sprout after the stem has died (Griffin 1971) makes it impossible to determine the original

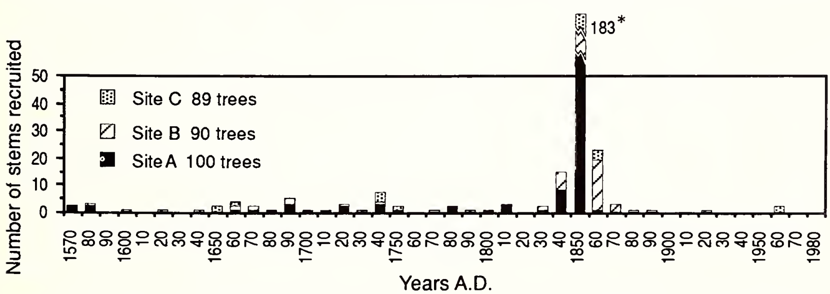

FIG. 2. Number of blue oaks recruited per decade for three sites on Tejon Ranch, Kern County, California. *Of the 183 trees recruited in the 1850's, 65 are from site "A", 50 from site "B", and 68 from site "C". More specifically, 156 trees date to the year 1856, including 61 from site "A", 44 from site "B", and 51 from site "C".

FIG. 3. Number of fire scars on blue oaks, per decade, for three sites on Tejon Ranch, Kern County, California.

date of acorn germination and seedling establishment. Ages assigned to trees in this study represent stem age and do not necessarily reflect the actual date of seedling establishment. As will be explained in the discussion, many of the existing trees probably represent sprouts from an existing root structure following the death of the former stem.

The pattern of tree recruitment is fairly continuous from 1570 to 1850, punctuated by a dramatic regeneration peak in the 1850's, and followed by an almost complete absence of recruitment since the 1860's (Fig. 2). Fifty-six percent (156) of the stems aged date to 1856. Only three percent (9) of the stems date to the period from 1864 to the present, and several of these were shrubby saplings less than three feet tall. Though the woodland included many small trees with basal diameters less than 20 cm, most of these were found to be over 100 years old. Five trees were over 400 years in age, with the oldest being 412 years.

Fire history analysis. Fire scars were found on sixty-nine trees. Sixteen trees had multiple scars, with one having seven. A chronolog-

TABLE 1. MEAN FIRE-FREE INTERVAL FOR THREE DIFFERENT LAND USE PERIODS AT THREE SITES ON THE TEJON RANCH, KERN COUNTY, CALIFORNIA, BASED ON FIRE SCARS IN BLUE OAKS. Land use periods are described as follows: 1680–1842 = California Indian period, 1843–1865 = Settlement transition period with a transient population at Fort Tejon, 1866–1987 = Tejon Ranch period with commercial livestock grazing and controlled access to the land.

Period	Site "A"	Site "B" Interval in years	Site "C"
1680 A.D.–1842 A.D.	9.6	13.6	12.5
1843 A.D.–1865 A.D.	3.3	3.8	5.8
1866 A.D.–1987 A.D.	13.5	20.3	18.0

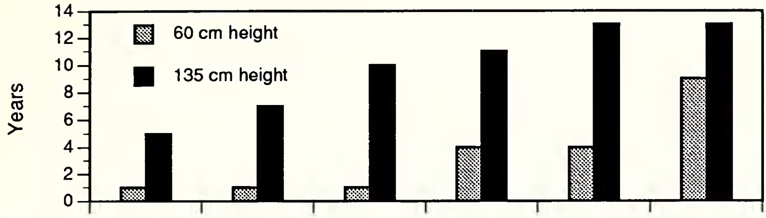

FIG. 4. Vertical growth rate for six blue oaks established in 1856, from Tejon Ranch, Kern County, California. Tree age was measured at the 60 and 135 cm heights.

ical graph of fire scars shows that fires occurred on a regular basis prior to the 1860's, with periodic peaks of increased frequency and a mean fire interval of approximately ten years or less, accounting for the probable absence of some fires from the scar record (Fig. 3). Fires were most common during the 1850's. After 1864, there was a complete absence of fire scars until the late 1920's, a span of more than 60 years. Mean fire interval during the period from 1843–1865 averaged four to five years (Table 1). Fires occurred every year from 1853 through 1856.

Vertical growth rates. In order to obtain an estimate of the vertical growth rates of trees established in 1856, several standing trees were cored at the base to determine their age. Six of these trees had become established in 1856. These six trees were then cored again at the 60 and 135 cm heights (McClaran 1986). The latter height is considered the browseline for cattle and deer, and is considered a critical point for sapling survival. All of the trees cored reached 135 cm within thirteen years (Fig. 4) with one growing to this height in only five years, a fairly rapid rate for blue oak.

Multiple centers. One third of all trees sampled had multiple centers. In the 1856 cohort, almost 40% had multiple centers. In all cases, each stem produced the same ring count, providing a single age for each tree.

DISCUSSION

Land use changes and oak regeneration. The results seem to suggest three distinct patterns of regeneration and recruitment that coincide with different periods of local land use. During the period of California Indian occupation, prior to European settlement, recruitment of new trees into the canopy was low but relatively continuous. The current mortality rate for California hardwoods has been estimated to be 0.3% (Bolsinger 1988). At this rate, recruitment of only five trees per hectare per decade would be sufficient to maintain these woodlands. Given the inevitable gaps in the record from mortality and heart rot, the data suggest that during the Indian period there was no regeneration and recruitment problem. Furthermore, recruitment appears to have been a continual process, rather than an episodic event.

During the mid 1800's, regeneration and recruitment were unusually successful, with a dramatic regeneration peak in 1856. This coincides with the initial phase of European settlement in the region. Four Mexican land grants were established in the 1840's; however, active European settlement did not begin until 1853 with the formation of Sebastian Indian Reservation, followed by the construction of Fort Tejon in 1854 (Giffen 1942; Crowe 1957). Fort Tejon housed up to 200 dragoons at any one time, and had a small population of merchants in the vicinity. The increase in human activity coincided with a dry period, as shown by narrow growth ring patterns and Sacramento precipitation records (McAdie 1903; Martin 1930). The increase in fire frequency during the 1850's–60's, with fires every year from 1853–56, is probably a result of increased ignitions by a transient population during a period of dry conditions.

Successful regeneration in the 1850's and 1860's is most likely the result of sprout growth rather than seedling establishment from acorns. In dry years, blue oak acorn germination is generally poor and few seedlings appear (Griffin 1971, 1980; McCreary 1989); however, under favorable conditions blue oak acorns readily germinate and establish seedlings. Subsequent drought, fire or predation often cause seedlings to die back, but they are capable of resprouting in the following growing season (Griffin 1971). The dry conditions present during this time period suggest that the regeneration peak was not due to the abundant establishment of seedlings, but more likely resprouting of seedlings and saplings burned by frequent fires.

Although mature blue oaks are fairly fire resistant, fire removes the above ground stem and foliage of saplings and seedlings (Lawrence 1966). Based on the relatively continuous recruitment of new trees into the woodland during the Indian period, it seems likely that seedlings, saplings, and small trees were present, and possibly abundant, when European settlement began. A series of fires would have removed the above ground portions of these small plants, initiating sprouting from the base. McClaran (1986) demonstrated that 70–85% of the blue oak in a stand may originate as sprouts within one year of a fire. By this process, fire temporally concentrates postfire sprouts (McClaran and Bartolome 1989). The 1856 regeneration peak provides clear evidence of this process.

Additional evidence for postfire sprouting is the high percentage of forked, or multiple-centered trees. In a previously cut blue oak stand, White (1966) found that 54% of the trees were forked below breast height, and suggested a high percentage of forking would be expected in a stand of sprouts. Almost 40% of the trees in the 1856 cohort were multiple-centered. Cutting as the mechanism stimulating sprouting is unlikely in this case since the site is remote, fuelwood is common, and there is no historical record of woodcutting in the area.

Successful recruitment. Successful sprouting does not necessarily result in recruitment of saplings and trees into the stand. Deer and livestock are capable of suppressing vertical growth for long periods by browsing young shoots and trampling seedlings. Repeated deer browsing has been shown to maintain blue oaks as small shrubs for as long as thirty years (Griffin oral communication). In the 1856 regeneration cohort, the six trees sampled for vertical growth rate all reached the browseline within thirteen years, with one surpassing this point in only five years. Clearly, vertical shoot growth does not appear to have been suppressed by browsing.

Historical evidence suggests that deer populations and browsing pressure were probably reduced during Fort Tejon's occupational period, from 1854–1864. The soldiers were known to have held hunting parties on a regular basis (Giffen 1942). The increase in hunting may have been enough to reduce the local deer population through mortality and migration.

McClaran and Bartolome (1989) have suggested that even under heavier livestock browsing pressure, plants that surpass the browseline (135 cm) in approximately 10–13 years will be recruited into the canopy. Postfire sprouts have been shown to grow almost twice as fast as other trees (McClaran 1986). A decade of reduced browsing pressure and rapid vertical growth were probably key factors contributing to the high rate of survival of the 1856 cohort.

A new period of land use began in the 1860's when General Edward Beale purchased all four Mexican land grants, consolidating the property under the control of one individual. Beale introduced commercial grazing in 1864, moving 14,000 head of sheep onto the property (Giffen 1942; Crowe 1957). Sheep were exchanged for cattle in the 1880's, and commercial grazing has continued to the present. Following the introduction of livestock, there was a sixty year period with a very low fire frequency. This decrease in fires was probably due to a reduction of ground fuels consumed by grazing livestock, combined with new efforts to control ignitions. While on a collecting trip, Grinnell (1905) noted, "... the whole of the country is fenced, and hunters and campers kept out for fear of starting fires or disturbing the stock." Cessation of fire further contributed to survival of stems recruited during the 1850's–60's, and resulted in an increase in tree density and canopy cover, similar to changes documented for oak woodlands on the prairie-forest border of the American Midwest after European settlers suppressed Indian fires (Cottam 1949). By 1930 when fire frequency increased, the trees were large enough to survive most ground fires.

Current lack of regeneration. Since the 1860's, almost no new trees have been recruited. A number of potential factors, or most likely, a combination of factors may be responsible for this. The introduction of commercial livestock grazing in the 1860's has probably had a negative effect on seedling establishment and sapling growth. Although McClaran (1986) did not find a clear relationship between presence of livestock and successful blue oak regeneration, in other studies cattle have been clearly identified with acorn and seedling mortality (Borchert et al. 1989; Rossi 1979), and reductions in recruitment (Harvey 1989).

The replacement of a perennial grass understory with introduced annual grasses may increase competition with oak seedlings for soil moisture, potentially reducing the available seedling bank (Gordon et al. 1989).

Intraspecific competition may contribute to lack of recruitment of saplings to trees. The flush of regeneration in the mid-19th century would have created a denser woodland than was present under Indian occupation, with an increase in canopy cover. Muick and Bartolome (1987) found that although 60% of blue oak seedlings grew under the canopy, 84% of all saplings were on the canopy edge or in the open. A reduction in openings may contribute to lack of sapling growth by decreasing suitable sites.

In summary, land use has changed significantly during the last two centuries; most important here are changes in fire frequency and the introduction of livestock and competitive annuals. This study has shown that the present stand structure is different from what existed during the pre-European period. The existing woodland is therefore not the result of an ongoing process of natural regeneration and recruitment, but of changes in land use practices, associated with European settlement. Vankat and Major (1978) reported a similar situation in Sequoia National Park, where an increase in blue oak density followed the demise of the Indians and the beginning of livestock grazing in the 1860's and 1870's. In this respect, lack of regeneration is perhaps a more complicated consequence of European settlement than has generally been recognized. It is not simply that grazing, changes in fire frequency, and competition from annuals have prevented regeneration, but furthermore that the density of stands themselves is an artifact of European impacts.

Acknowledgments

This research would not have been possible without the generous assistance of Don Geivet and the staff at Tejon Ranch. I thank Roger Byrne for providing direction in this research and for critical review of this paper, Ted Oberlander for helpful suggestions on an earlier version, and Joe McBride for direction and assistance in field work and data analysis, and review of an earlier version. I also thank Jim Griffin and Lynne Dee Oyler for helpful reviews. The map was produced by Alain Boutefeu whose assistance and skill is appreciated.

Literature Cited

Bartolome, J. W., P. C. Muick, and M. P. McClaran. 1987. Natural regeneration of California hardwoods. Pp. 26–31 *in* T. R. Plumb and N. H. Pillsbury (tech. coords.), Proceedings of the symposium on multiple-use management of California's hardwood resources. USDA Forest Service Pacific Southwest Forest and Range Experiment Station. General technical report PSW–100. 462 p.

Borchert, M. I., F. W. Davis, J. Michaelsen, and L. D. Oyler. 1989. Interactions of factors affecting seedling recruitment of blue oak (*Quercus douglasii*) in California. Ecology 70:389–404.

Bolsinger, C. L. 1988. The hardwoods of California's timberlands, woodlands and savannas. USDA Forest Service Pacific Northwest Research Station. Research bulletin PNW-RB-148. 148 p.

Cottam, G. 1949. The phytosociology of an oak woods in southwestern Wisconsin. Ecology 30:271–287.

——— and J. T. Curtis. 1956. The use of distance measures in phytosociological sampling. Ecology 37:451–460.

Crowe, E. 1957. Men of El Tejon. The Ward Ritchie Press, Los Angeles. 165 p.

Fritts, H. C. 1976. Tree rings and climate. Academic Press, New York, NY.

Giffen, H. S. 1942. The story of El Tejon. Dawsons Book Shop, Los Angeles, CA. 146 p.

Gordon, D. R., J. R. Welker, J. W. Menke, and K. J. Rice. 1989. Competition for soil water between annual plants and blue oak (*Quercus douglasii*) seedlings. Oecologia 79:533–541.

Griffin, J. R. 1971. Oak regeneration in the upper Carmel Valley, California. Ecology 52:862–868.

———. 1980. Animal damage to valley oak acorns and seedlings, Carmel Valley, California. Pp. 242–245 *in* T. R. Plumb (tech. coord.), Proceedings of the symposium on the ecology, management, and utilization of California oaks. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. General technical report PSW-44. 368 p.

——— and W. B. Critchfield. 1972. The distribution of forest trees in California. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. Research paper PSW-82. 114 p.

Grinnell, J. 1905. Old Fort Tejon. Condor 7:9–13.

Harvey, L. E. 1989. Spatial and temporal dynamics of a blue oak woodland. Ph.D. dissertation. University of California, Santa Barbara. 170 p.

Lawrence, G. E. 1966. Ecology of vertebrate animals in relation to chaparral fire in the Sierra Nevada foothills. Ecology 47:278–291.

Martin, R. J. 1930. Climatic summary of the United States: section 16-northwestern California: section-17 central California: section 18-southern California. USDA Bureau of Agriculture and Weather, Government Printing Office, Washington, D.C.

McAdie, A. G. 1903. Climatology of California. USDA Bureau of Agriculture and Weather, Bulletin L, Government Printing Office, Washington, D.C.

McBride, J. R. 1983. Analysis of tree rings and fire scars to establish fire history. Tree-Ring Bulletin 43:51–67.

——— and D. F. Jacobs. 1980. Land use history in the mountains of southern California. Pp. 85–89 *in* Proceedings of the fire history workshop. USDA Forest Service. Technical Report RM-81.

McClaran, M. P. 1986. Age structure of *Quercus douglasii* in relation to livestock grazing and fire. Ph.D. dissertation. University of California, Berkeley. 119 p.

——— and J. W. Bartolome. 1989. Fire-related recruitment in stagnant *Quercus douglasii* populations. Canadian Journal of Forestry 19:580–585.

McCreary, D. D. 1989. Regenerating native oaks in California. California Agriculture 43(1):4–6.

Muick, P. C. and J. W. Bartolome. 1987. An assessment of natural regeneration of oaks in California. Final Report. California Department of Forestry: Forest and Rangeland Assessment Program. 100 p.

Romme, W. H. 1980. Fire history terminology: report of the ad hoc committee. Pp. 135–137 *in* M. A. Stokes and J. H. Dietrich (eds.), Proceedings of the fire history workshop. USDA Forest Service. General technical report RM-81.

Rossi, R. S. 1979. Land use and vegetation change in the oak woodland-savanna of northern San Luis Obispo County, California (1774–1978). Ph.D. dissertation, University of California, Berkeley. 337 p.

Vankat, J. L. and J. L. Major. 1978. Vegetation changes in Sequoia National Park, California. Journal of Biogeography 5:377–402.

USDA Soil Conservation Service with the University of California. 1981. Soil survey of Kern County, Southeastern Part. Agricultural Experiment Station.

White, K. L. 1966. Structure and composition of foothill woodlands in central coastal California. Ecology 47:229–237.

(Received 19 Nov 1990; revision accepted 7 June 1991.)

ANNOUNCEMENT

Recent Publications

Response of Plants to Multiple Stresses. Edited by H. A. Mooney, W. E. Winner. 1991. Physiological Ecology, A Series of Monographs, Texts, and Treatises. Academic Press, Inc. San Diego, CA. xiv + 422 p. hardcover, ISBN 0-12-505355-X.

Plant Taxonomy. The Systematic Evaluation of Comparative Data. 1990. By T. F. Stuessy, Columbia University Press, New York. xvii + 514 p. hardcover, ISBN 0-231-06784-4.

Ancient Forests of the Pacific Northwest. 1990. By Elliott A. Norse, Island Press, Covelo, CA. xxii + 327 p. softcover, ISBN 1-55963-017-5.

Free Market Environmentalism. 1991. By Terry L. Anderson and Donald R. Leal, Pacific Research Institute for Public Policy, San Francisco, CA. xii + 192 p. softcover, ISBN 0-8133-1101-2.